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published in
XVth Triennial Congress of the International Ergonomics Association
2003

THE INFLUENCE OF LOAD POSITION AND LIFTING TECHNIQUE ON LOW BACK LOADING DURING LIFTING.

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The aim of this study was to quantify the effect foot position relative to a load on the loading of the low back in terms of net moments and compression forces at the L5S1 joint during stoop and squat lifting. In addition, stoop and squat lifting are compared to a free lifting technique and to a technique (weight lifters technique) where the feet and knees are rotated outward. When lifting a load from the ground, it was found that squat lifting causes higher moments and compression forces than stoop lifting, both when lifting a load in front of the feet and when lifting a load between the feet. The free technique and the 'weight lifters' technique caused peak low back loading in between the values that where found for squat and stoop lifting.

INTRODUCTION

Mechanical loading of the low back is thought to be an important risk factor for the development of low back pain. Manual materials handling, like lifting objects from the floor causes compressive forces at the spine that could exceed the tolerance level of the intervertebral joints (Waters *et al.*, 1993). Therefore, many ergonomic studies have investigated determinants of low back loading, usually by quantifying back loading in terms of net moments or compression forces. For some determinants, like object weight, lifting speed and horizontal and vertical (initial and final) position of the object relative to the worker, substantial evidence has been presented showing their influence on lumbar loading (e.g., (de Looze *et al.*, 1994, Kingma *et al.*, 2001, Dolan *et al.*, 1994, Lavender *et al.*, 2003). One other factor that has been investigated in many studies is the lifting technique. Practitioners often recommend lifting objects by bending the knees (squat technique) rather than by bending the back (stoop technique). Early studies, using static biomechanical models (linked segment models) indeed suggested that lumbar spine loading was somewhat lower in squat lifting than in stoop lifting. However, dynamic linked segment models usually predict an equal or even higher lumbar load in squat lifting compared to stoop lifting (for an overview, see van Dieën *et al.*, 1999). One reason for this difference could be that accelerations, which are ignored in static models, are larger in squat lifting than in stoop lifting. Another reason could be that, in studies using static models and finding a lower back load in squat lifting, the load was positioned between the feet during squat lifting but not during stoop lifting (van Dieën *et al.*, 1999). Using dynamic linked segment models, the interaction between lifting technique and load position has not yet thoroughly been investigated. The aim of this study was therefore to establish the effect of load position (i.e. placing the load either in front of the feet or between the feet), both in squat lifting and in stoop lifting. In addition, since box size may interact with effects of lifting technique and load position, two boxes of different size but equal weight were used. Finally, the stoop and squat lifting technique were compared to a weight lifters technique, which had not yet been investigated. In this technique, the feet are placed in front of the load, and the feet and knees are rotated laterally. This technique might reduce the horizontal distance between the pelvis and the load. Lumbar loading was quantified using a dynamic 2D linked segment model to estimate net moments at the L5S1 joint. This model was coupled to an EMG driven detailed model of the trunk, to estimate compressive forces at the L5S1 joint.

METHODS

Subjects and procedure

Ten young male subjects participated in the experiment after signing an informed consent. All subjects performed two repetitions of 16 lifting movements, differing in lifting technique, foot position relative to the box, and box size. All conditions are summarized in Table 1.

Cond. nr	Technique	box	Feet
1	Free	L	Free
2	Free	S	Free
3	Squat	L	Free
4	Squat	S	Free
5	Squat	S	Side
6	Squat	S	Front
7	Squat	L	Front
8	Squat	L	Side
9	Stoop	L	Free
10	Stoop	S	Free
11	Stoop	S	Side
12	Stoop	S	Front
13	Stoop	L	Front
14	Stoop	L	Side
15	WL	L	Free
16	WL	S	Free

Table 1: specification of lifting movements that were performed by 10 subjects in the experiment. Each lifting movement was performed twice.

Four different lifting techniques were used. The first technique was always a free technique, where subjects could place their feet where they liked and bent their knees as far as they liked. To prevent influence of previous instructions on the free lifting technique, each subject started with the free lifting technique. Subsequent lifting movements were performed in randomized order. The other lifting techniques were a squat technique (bending the knees while holding the back as upright as possible), a stoop technique (lifting with the knees extended) and a 'Weight Lifters' technique (WL). In the latter technique subjects were instructed (through video, to standardize instruction) to rotate their feet and knees about 45 degrees outward, and to maintain a lumbar lordosis while lifting. In the WL technique the feet were placed in front of the box. Three foot placing instructions were given for both the squat and the stoop lifting technique, with both the large and the small box. Those foot placing instructions were: free, front (feet in front of the box) and side (feet at the left and right side of the box). The dimensions of the large and the small box were 330x230x200 mm and 480x340x330 mm (width x height x depth). Both boxes weighted 10.5 kg. The boxes had no handles. Subjects therefore had to grab the boxes at the bottom. Notches at the bottom left and right side allowed an easy and firm grip on the box.

Measurements

Ground reaction forces were measured at 75 Hz using a custom-made 1x1 m forceplate. Movements of body segments were measured at 75 Hz using an automated 3D movement registration system (Optotrak), with two arrays of three cameras. LED markers were placed on the left side of the body at the foot (fifth metatarsal joint), the ankle (lateral malleolus), the knee (lateral epicondyle), the hip (greater trochanter), the L5S1 joint (according to (de Looze *et al.*, 1992), the spinous process at T1, the shoulder joint (just below the acromion), the elbow joint (lateral epicondyle) and the wrist joint. In addition, three LED markers were placed on each box. Segment inertial parameters were obtained according to Plagenhoef et al. (1983). A 2-D dynamic linked segment model was used to calculate net moments and reaction forces at the L5-S1 joint.

Surface EMG electrodes were attached to the skin after abrasion and cleaning with alcohol (Ag/AgCl electrodes at an inter-electrode distance of 20 mm). Electrodes were bilaterally attached over two locations of the back muscles (3 cm lateral to L3 and 5 cm lateral to T10) and at five locations over the abdominal muscles: the internal oblique (dorsal and lateral), the external oblique (lateral and anterior) and rectus abdominus. EMG data were sampled at 1000 Hz, and synchronized with forceplate and optotrak recordings.

EMG data were normalized to maximum voluntary contractions and used as input of an EMG driven trunk muscle model. The model has been described in more detail previously (van Dieën, 1997), and consists of a compilation of anatomical data described by Stokes and Gardner Morse (1995) for the back muscles and by McGill (1996) for the abdominal muscles. After exclusion of the transversus abdominis, the psoas major muscle and the latissimus dorsi muscle, the model consisted of 90 muscle slips crossing the L5S1 joint. The model was scaled to individual body height. For muscle slips crossing the L4 and T12 level, nodes were used to keep the distance between those vertebrae and the muscles constant, in order to let the muscles follow the lumbar curvature during motion.

Muscle forces were estimated as the product of the maximum muscle stress, normalized EMG amplitude and correction factors for the instantaneous muscle length and contraction velocity. These correction factors are based on dynamical properties of human and animal muscles as described by van Zandwijk (1998) and passive length tension properties as described by Woittiez et al. (1984). The muscle lengths and contraction velocities were calculated on the basis of the angle between the pelvis and the trunk.

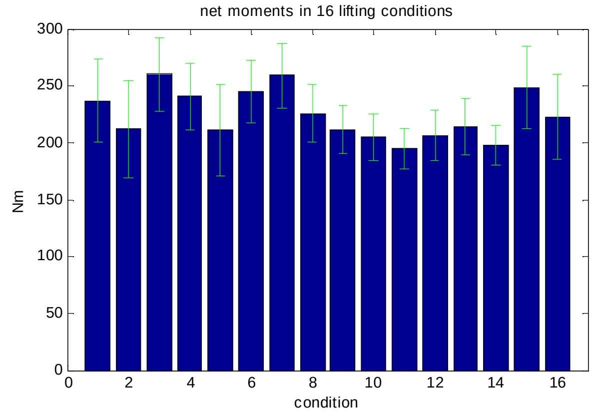
To obtain forces at the L5S1 intervertebral disc, muscle forces and net reaction forces were added after projecting them on the estimated sacral axis system.

Statistics

Because the design of the complete experiment was not balanced (only one foot position was measured for the WL technique), repeated measures ANOVA's were applied to two subsets of the data with a balanced design. The effect of foot position was tested with stoop and squat lifts only (ANOVA 1). The four lifting techniques were compared using only the conditions where the instruction was to place the feet in front of the box (ANOVA 2).

RESULTS

When comparing the pattern of low back loading over all lifting conditions (Figure 1), net moments and L5S1 compression forces showed similar tendencies. ANOVA 1 revealed a higher moment (5%) and compression force (6%) in lifting the large box compared to the small box ($p < 0.001$). Furthermore, lifting with the feet in front of the box caused a higher moment (11%) and compression force (12%) compared to lifting with the feet on both sides of the box ($p < 0.001$). Averaged over all three foot positions, the squat lift resulted in a higher moment (17%) and compression force (26%) compared to the stoop lift ($p < 0.001$). There was no difference between the free foot position and the foot position in front of the load, because subjects always placed their feet in front of the box when the foot position was free. For the moment as well as the compression force, the effect of foot position (front versus side) was slightly stronger for the squat lift than for the stoop lift ($p < 0.001$). For the squat lift, the moment reduced with 13% and the compression force reduced with 16% when lifting with the feet on the side instead of in front of the box. For the stoop lift those reductions were 7% and 5%, respectively. Still, with the feet placed at the sides of the box, squat lifting resulted in 11% higher moments and 14% higher compression forces compared to stoop lifting. The free lifting technique and the WL technique caused moments and compression forces in between the values for squat lifting and stoop lifting.



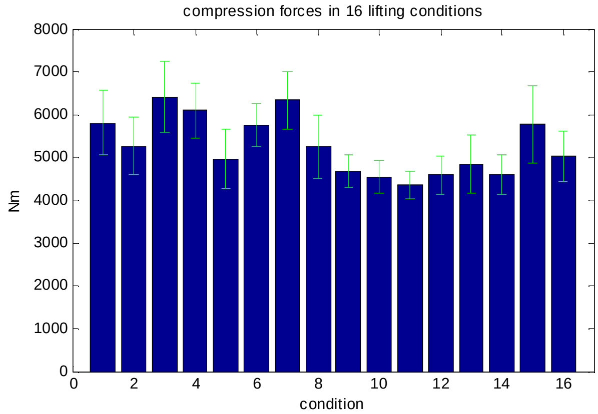


Figure 1. Peak net moments (top) and estimated compression forces (bottom) at the L5S1 joint under 16 different lifting conditions. Lifting conditions are specified in Table 1.

DISCUSSION

This study compared low back loading over four different lifting techniques, and investigated the effect of initial load position on low back loading in squat and stoop lifting. As has been reported before, low back loading was found to be lower with the load between the feet than with the load in front of the feet (e.g., Dolan *et al.*, 1994) and lower in stoop lifting than in squat lifting (e.g., de Looze *et al.*, 1998, Kingma *et al.*, 2001). The current study also showed that when lifting from the floor, foot position affected low back loading more in squat lifting than in stoop lifting. However, the net moment as well as the compression force remained higher in squat lifting than in stoop lifting, also when the load was lifted between the feet.

The WL technique, which intends to reduce low back loading during squat lifting by rotating the feet and knees outward and thereby bringing the pelvis close to the load, was only moderately successful, in that it indeed reduced low back loading but not below or even down to the level that is obtained during stoop lifting.

For practical purposes, the current study reinforces the advice to lift loads between the feet when lifting from the ground. The WL technique is, from the point of view of low back loading, to be preferred over the squat technique. It remains unclear whether the advantage of lower moments and compression forces in stoop lifting is outweighed by increased bending forces (Adams *et al.*, 1994) and increased shear forces in fully flexed posture.

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